PATENT
Attorney Docket No.: 8G09.1-011

NON-PROVISIONAL APPLICATION FOR LETTERS PATENT

UNITED STATES OF AMERICA

TO ALL WHOM IT MAY CONCERN:

Be it known that, ***BRUNO S. MARCOCCIA,*** residing at 619 Bellenden, Peachtree City, Georgia 30269, and ***JAMES ROBERT PROUGH***, residing at 22 Ferndell Spring Drive, Saratoga, New York 12866, both citizens of the United States of America, have invented new and useful improvements in a

SYSTEM AND METHOD FOR IMPROVED FILTRATE ADDITION IN A CONTINUOUS DIGESTER

for which the following is a specification.

SYSTEM AND METHOD FOR IMPROVED FILTRATE ADDITION IN A CONTINUOUS DIGESTER

RELATED APPLICATION

This application claims priority to and the benefit of U.S. Patent Application Serial No. 60/211,941, filed June 16, 2000, which is hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

This invention relates generally to continuous digesters that digest cellulosic fibrous material and produce cellulosic pulp. More particularly, this invention relates to an improved filtrate addition system and method for use in and with a continuous digester. The system and method of this invention produce a heretofore unseen uniform filtrate distribution in the blow dilution zone of the digester.

BACKGROUND OF THE INVENTION

In continuous digester systems, the uniformity of the filtrate flow discharge has a substantial impact on the overall process performance.

In particular, distribution of filtrate in the blow dilution zone of continuous digester systems may impact internal heat recovery efficiency, washing efficiency, blow consistency control, blow temperature control, column movement patterns, column movement uniformity, cooking uniformity, and screened yield.

Non-uniform distribution of filtrate due, for example, to plugged nozzles will cause non-ideal conditions where localized velocity variations of several hundred percent are possible. These velocity gradients result in significant localized gradients in drag force, thus causing the column to slow in areas of high filtrate introduction and speed up in areas of low or no filtrate introduction. Once such a pattern is established, it is likely self-reinforcing.

There are typically three locations where filtrate is introduced in the blow dilution zone of a conventional continuous digester: the side dilution header/nozzle assembly, the bottom head dilution header/nozzle assembly, and the outlet device.

In most cases, the majority of filtrate is introduced and distributed via the side dilution header/nozzle assembly. The distribution and flow of filtrate through these locations directly influences blow consistency, blow temperature and dilution factor.

Previously, it was an impractical task to manually keep clear all the nozzles of a conventional, unmodified digester header/nozzle assembly. As soon as the digester conditions changed, particularly during upsets, another nozzle would plug. However, in spite of the obvious importance of uniform filtrate distribution, the present continuous digesters operate with little or no control of filtrate flow distribution and in turn continue to produce non-uniformity. Therefore, a need exists for an improved filtrate addition system and method that produces a uniform filtrate distribution in a continuous digester.

SUMMARY OF THE INVENTION

The present invention relates to a system and method that improves the filtrate flow distribution of a continuous digester. To overcome the problems outlined above, and in one form of this invention, a plurality of individual flow measurement and control devices are added to a filtrate header/nozzle assembly of a continuous digester. The objective of this modification is to improve overall digester process performance by improving the distribution and control of filtrate added in the blow dilution zone at the bottom of the digester. This modification to the filtrate addition system results in the elimination of plugged nozzles and has improved energy efficiency. Operating data also shows major improvements in column movement, digester stability, washing efficiency, heat recovery efficiency, and cooking uniformity. This invention may be applied to the majority of, if not all, continuous digester systems.

In accordance with the purposes of this invention, as embodied and broadly described herein, this invention, in one aspect relates to a filtrate addition system for producing a uniform filtrate distribution in the blow dilution zone of a continuous digester comprising (a) a blow dilution header/nozzle assembly located in the blow dilution zone comprising (i) a plurality of nozzles for introducing and distributing filtrate into the blow dilution zone, and (ii) a plurality of measurement and control devices for monitoring and controlling filtrate flow through the plurality of nozzles.

In another aspect, this invention relates to a filtrate addition system for producing a uniform filtrate distribution in the blow dilution zone of a continuous digester comprising (a) a blow dilution header/nozzle assembly located in the blow dilution zone comprising (i) a side dilution header/nozzle assembly having a plurality of nozzles for introducing and distributing filtrate into the blow dilution zone and at least one measurement and control device corresponding to the nozzles for monitoring and controlling filtrate flow therethrough, and (ii) a bottom dilution header/nozzle assembly having a plurality of nozzles for introducing and distributing filtrate into the blow dilution zone and at least one measurement and control device corresponding to the nozzles for monitoring and controlling filtrate flow therethrough, wherein the at least one measurement and control device of the side header/nozzle assembly is independent from the at least one measurement and control device of the bottom header/nozzle assembly.

In another aspect, this invention relates to a filtrate addition system for producing a uniform filtrate distribution in the blow dilution zone of a continuous digester comprising (a) a blow dilution header/nozzle assembly located in the blow dilution zone comprising (i) a side dilution header/nozzle assembly having a plurality of nozzles for introducing and distributing filtrate into the blow dilution zone and a measurement and control device corresponding to each nozzle of the plurality of nozzles for monitoring and controlling filtrate flow therethrough, and (ii) a bottom dilution header/nozzle assembly having a plurality of nozzles for introducing and distributing filtrate into the blow dilution zone and a measurement and control device corresponding to each nozzle of the plurality of nozzles for monitoring and controlling filtrate flow therethrough.

In yet another aspect, this invention relates to a method for producing a uniform filtrate distribution in the blow dilution zone of a continuous digester comprising (a) introducing and distributing filtrate through a plurality of nozzles of a blow dilution header/nozzle assembly in the blow dilution zone of the continuous digester; and (b) measuring and controlling the filtrate flow through each nozzle of the plurality of nozzles.

Additional advantages of the invention will be set forth in part in the figures and detailed description, which follow, and in part will be obvious from the description, or may be learned by practice of the invention. The advantages of the

invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory of preferred embodiments of the invention, and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an exemplary continuous digester system according to the present invention, shown interconnected to other components of a mill for producing cellulose pulp.

FIG. 2 is a schematic view of the blow dilution zone of an exemplary continuous digester.

FIG. 3(a) is a schematic plan view of a prior art header/nozzle assembly device.

FIG. 3(b) is a schematic plan view of an exemplary header/nozzle assembly device according to one embodiment of the present invention.

FIG. 3(c) is a schematic view of an exemplary device for monitoring, measuring and controlling filtrate flow according to the present invention.

FIG. 4 is a graph of heat recovery efficiency as a function of wash dilution factor (DF) comparing an unmodified filtrate addition system and a modified filtrate addition system of the present invention.

FIG. 5 is a graph of blow line heat loss as a function of operating conditions and wash zone DF comparing an unmodified filtrate addition system and a modified filtrate addition system of the present invention.

FIG. 6 is a graph of total medium pressure steam demand as a function of operating conditions and wash zone DF comparing an unmodified filtrate addition system and a modified filtrate addition system of the present invention.

FIG. 7 is a graph of blow line temperature gradients before and after filtrate header/nozzle assembly modification according to the present invention.

FIG. 8 is a graph of modified cook header/nozzle assembly temperature gradients before and after filtrate header/nozzle assembly modification according to the present invention.

FIG. 9 is a graph of extraction header/nozzle assembly temperature gradients before and after filtrate header/nozzle assembly modification according to the present invention.

FIG. 10 is a graph of the effect on cooking uniformity of the filtrate header/nozzle assembly modification according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention may be understood more readily by reference to the figures, detailed description, and the examples, which follow, where like reference numerals represent like elements throughout. It is to be understood that this invention is not limited to the specific methods, conditions and/or parameters described, as specific methods and/or method conditions and parameters may, of course, vary. It is also understood that the terminology used herein is used for the purpose of describing particular embodiments only and is not intended to be limiting. It must also be noted that, as used in the specification including the appended claims, the singular forms "a," "an," and "the" include plural references, unless the context clearly dictates otherwise.

Ranges may be expressed herein as from "about" or "approximately" one particular value and/or to "about" or "approximately" another particular value. When such a range is expressed, another embodiment includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent "about," it will be understood that the particular value forms another embodiment.

Description of General Process

In standard continuous digester systems, filtrate is introduced and distributed in the bottom of the continuous digester in the area known as the blow dilution zone. This is an important unit operation that has pronounced effects on process stability, control and efficiency of the pulping process. "Filtrate" refers to the flow extracted

from the downstream brownstock washing device. This flow of washer-extracted liquor is brought counter-currently backwards to the digester where it is used simultaneously for in-digester washing and dilution within the blow dilution zone of the digester vessel. The "blow dilution zone" of a continuous digester refers to the zone in the bottom of the digester from the discharge (i.e., the very bottom of the vessel) up to the bottom of the wash circulation screens. The blow dilution zone contains all filtrate dilution nozzles as well as the outlet device. Within this zone, the down-flowing pulp/liquor reaction mixture is diluted, cooled and discharged out of the vessel through the blowline. The outlet device typically consists of a cone with scraper arms attached to it, and it rotates in order to facilitate discharge of the cooled, diluted pulp.

The following processes typically, but not necessarily occur in the blow dilution zone of a continuous digester:

- Down-flowing hot chips (pulp) and liquor are cooled and diluted prior to discharge to permit cold blowing;
- Filtrate is distributed across the vessel and is heated as it rises within the counter-current wash zone;
- Flow patterns for up-flowing (counter-current) liquor are established;
- Flow patterns for down-flowing pulp slurry are established; and
- An upflow/downflow interface is established.

For continuous digester systems operating with extended, modified cooking, similar to that shown in **FIG. 1**, white liquor and heat are distributed in the wash circulation. The wash circulation screen assembly is immediately above the blow dilution zone, typically one (1) to two (2) meters above the filtrate addition point. Conditions in the blow dilution zone have a direct impact on cooking chemical distribution and energy in the final cooking stage of the process.

The simultaneous cooling of fully cooked chips and heating of filtrate via direct heat exchange recovers almost as much energy as the re-use of flash steam for chip steaming. Moreover, heat recovery through chip-to-filtrate exchange displaces medium pressure steam whereas a typical flash heat recovery system displaces low pressure steam. In most pulp mills, the medium pressure steam is of greater value.

Both heat recovery efficiency and washing efficiency in the counter-current wash zone are directly related to the uniformity of filtrate distribution across the

column diameter. The mechanism for both is direct, counter-current contact between filtrate and chips. The uniformity of filtrate distribution depends on, among other things:

- The uniformity of filtrate flows at the introduction point;
- The efficiency of the wash circulation system; and
- Chip and liquor patterns of flow (plug flow vs. channel).

Note that these three factors have strong interactions.

Since heating typically occurs in the wash circulation, an efficient wash circulation will actually diminish heat recovery efficiency. When filtrate is heated within the circulation heater, it loses the opportunity to fully exchange temperature via the direct contact, counter-current chip-to-filtrate heat exchange mechanism.

There are typically three locations in the blow dilution zone where filtrate is introduced through a blow dilution header/nozzle assembly assembly: the side dilution header/nozzle assembly, the bottom head dilution header/nozzle assembly, and the outlet device arms. Each of these header/nozzle assemblies of the header/nozzle assembly preferably has a series or plurality of nozzles. In most cases, the majority of filtrate is introduced via the side dilution nozzles, for example. The distribution and flow of filtrate through these locations directly influences blow consistency, blow temperature and dilution factor.

Uniformity of filtrate distribution also influences chip column and liquor flow patterns in the cooking zones above the blow dilution zone. Downward flow of the chip column is driven by gravity and resisted by frictional forces and drag forces. The downward force is proportional to the difference in density between the chip and the surrounding, external liquor phase. Since more than 75% of the fully cooked chip is internally occupied by liquor at the end of the cook, this density difference is very small at the bottom of the digester. The drag force is proportional to counter-current liquor velocity, which can be quite high at the bottom of a digester.

However, non-uniform distribution of filtrate due, for example, to plugged nozzles will cause non-ideal conditions where localized velocity variations of several hundred percent are possible. These velocity gradients result in significant localized gradients in drag force, thus causing the column to slow in areas of high filtrate introduction and speed up in areas of low or no filtrate introduction. Once such a pattern is established, it is typically self-reinforcing. For example, if a system has a

localized downflow zone and an opposing, localized upflow zone, then the column will tend to further compact in the downflow zone and further loosen up in the upflow zone. Filtrate will preferentially follow the path of least resistance (the less compacted zone), causing more drag in the upflow zone and thus stabilizing the channel flow pattern.

Channel flow of chips and/or liquor causes variations in the residence time, cooking chemical profile, and temperature profile experienced by chips passing through different zones of the digester. This in turn causes variability in extent of reaction. In the extreme case, this specific type of cooking non-uniformity results in higher reject contents and lower screened yield. Generation of reject vs. kappa curves is an indirect method for measurement of such non-uniformity.

The discussion above summarizes how the distribution of filtrate in the blow dilution zone of a continuous digester impacts internal heat recovery efficiency, washing efficiency, blow consistency control, blow temperature control, column movement patterns, column movement uniformity, cooking uniformity, and screened yield. In spite of the obvious importance of uniform filtrate distribution, the majority of continuous digesters are presently operated with no targeted control of filtrate flow distribution.

The Pulping System

Referring particularly to **FIG. 1**, and to provide an example and overview of a pulping system and process, the filtrate addition system of the present invention is installed on a two-vessel hydraulic 1200 admt/d system operated in an Extended Modified Continuous Cooking (EMCC™) mode, shown generally at 15. The digester comprises a top and a bottom, an inlet at the top for receiving cellulosic fibrous material and an outlet at the bottom for discharging digested pulp.

In particular, the digester system 15 is fed wood chips from wood yard area 17. The wood chip stream 20 is fed to the digester feed system 30. A chip-liquor slurry 40 is fed to the top of digester vessel 70 having a chip-liquor separator 50. A liquor return stream 60 is fed back to the digester feed system 30.

The digester system 15 has a primary heating circulation system 90 and a secondary heating circulation system 100, both with an indirect liquor heater. A

circumferential screen assembly for cook liquor withdrawal is located at 80a-c along the length of vessel 70. Liquor is withdrawn from locations 80a and 80c and circulated to heating systems 90 and 100, and re-circulated back to the vessel 70. The circumferential screen assembly 80b for cook liquor withdrawal is approximately mid-vessel and extracts a spent cooking liquor stream 110 and directs that stream to a liquor evaporation area 120. After evaporation, concentrated, spent (or "Black") liquor 130 is directed to chemical recovery and preparation areas 140. A "white" liquor stream 150 (cooking chemical) is fed to digester feed system 30 for forming a chip-liquor slurry for introducing into the top of vessel 70.

The blow dilution zone of vessel 70 is shown generally at 160. Blow dilution zone 160, located around the bottom area of digester vessel 70, has a side dilution header/nozzle assembly 170 and a bottom head dilution header/nozzle assembly 180. At the very bottom of the vessel 70, a blowline 190 containing a pulp/water slurry stream directs the slurry to a "brownstock" washing and screening area 200. Wash water 210 is added to the brownstock washing and screening area 200. From area 200, filtrate 220 (also called cold blow filtrate or wash filtrate) is directed from the wash to the digester's blow dilution zone 160. Washed brown stock pulp/water slurry 230 is directed from the washing and screening area 200 to bleaching and/or drying and/or paper making areas 240.

Cooking chemical is added at both the wash and MCC™ circulations. Simultaneous counter-current cooking and washing take place in the zones between the extraction and wash screens. Cooking retention time is between 4.5 and 5.5 hours, with approximately 3.5 to 4 hours retention in the counter current zones.

Not shown in **FIG. 1**, but following digester 15 typically is a 2-stage atmospheric diffuser, pressurized screen room and vacuum washer. A 2-stage medium consistency oxygen delignification system followed by atmospheric diffuser and vacuum washer complete the brownstock fiberline system. The fiberline system produces several grades of softwood market pulp from a variety of coastal and interior wood furnishes.

Filtrate Addition System and Modifications

Referring particularly to **FIGS. 1 and 2**, there are typically three locations in the blow dilution zone, shown generally at 160, where filtrate is introduced and

distributed through a blow dilution header/nozzle assembly: the side dilution header/nozzle assembly 170, the bottom head dilution header/nozzle assembly 180, and the outlet device 145. Each of these particular header/nozzle assemblies of the overall header/nozzle assembly preferably has a series or plurality of nozzles. In particular, side dilution header/nozzle assembly 170 typically has 12 horizontal nozzles equally spaced around the circumference. Bottom head dilution header/nozzle assembly 180 typically has 4 to 8 vertical nozzles spaced evenly around the bottom head. Outlet device 145 comprises a rotator cone/scraper arms assembly. In most cases, the majority of filtrate is introduced via the side dilution nozzles of the blow dilution zone 160. Blow dilution zone 160 is defined as the vessel volume between the bottom of the wash screens and the bottom of the vessel, or the vessel discharge. Zone 160 contains all dilution nozzle entry points and the outlet device 145.

To more particularly point out the flow of a digester system and the blow dilution zone 160, the digester vessel has a shell 105. Within shell 105, and shown at 25, a con-current cook zone houses wood chips and liquor wherein the chips and liquor move down. Moving down the vessel, circumferential screens 80b is shown. Screens 80b screen for spent liquor withdrawal and is typically referred to as an extraction screen. Associated with circumferential screens 80b is an extraction screen header/nozzle assembly 45 (typically has 4 horizontal nozzles). From extraction screen header/nozzle assembly 45, spent cooking liquor streams to evaporators.

Below circumferential screen 80b is a counter-current wash zone 65. In this zone, chips move down, liquor moves up. This zone may also be operated con-currently.

Below counter-current wash zone 65 are circumferential screens 80c. Screens 80c screen for spent liquor withdrawal and are typically referred to as wash screens. Associated with circumferential screens 80c is a wash screen header/nozzle assembly 85 (typically has 12 nozzles) including a wash circulation pump 95 and wash circulation heater 100. From wash screen header/nozzle assembly 85, wash circulation liquor returns through return line 115.

At the very bottom of the vessel 70, a blowline 190 containing a pulp/water slurry stream directs and discharges the slurry to a "brownstock" washing and screening area 200. Filtrate 220 (also called cold blow filtrate or wash filtrate) is directed to the digester's blow dilution zone 160, including to outlet device 145 through line 165.

Many conventional digesters normally operate with from about 15 to about 50% of the filtrate addition nozzles plugged. A typical, known side header/nozzle assembly design (**FIG. 3(a)**) comprises a single inlet 16 branching to a relatively large, constant diameter, horseshoe header/nozzle assembly 175 with twelve (12) evenly spaced small diameter nozzles having manual isolation valves, shown at 66a-l. The known assembly also includes a pressure indication control loop 22, an automatic valve 33 for flow adjustment, and a flow indicator/transmitter device 44. The assembly 175 also has a pressure indicator/transmitter device 88 within digester shell 105.

As explained above, typically, but not necessarily, there are 4 to 8 nozzles off the bottom head dilution header/nozzle assembly of the overall blow dilution header/nozzle assembly. The individual nozzle lines typically have a manual isolation valve between the header/nozzle assembly outlet and digester inlet 16.

However, the standard or conventional side header/nozzle design (**FIG. 3(a)**) is prone to plugging. One reason for plugging is the flow velocity decrease along the length of the side header/nozzle assembly 175. The driving force for filtrate to enter the digester from filtrate flow-in 16 through the rear-most nozzles (e.g., 66a, 66b, 66k and 66l) is lower than for preceding nozzles (e.g., 66c-j). Once relative flow through any nozzle decreases, the amount of dilution at that location will decrease, the column will "thicken," and the driving force required for filtrate introduction increases. Once non-uniform flow patterns are established they become self-reinforcing and ultimately lead to nozzle plugging. Plugging is also caused by the accumulation of fiber at the ends of the "horseshoe-shaped" dilution header/nozzle assembly 175 and within the nozzles 66a-l. The fiber source may be the filtrate or it may originate from within the digester, coming out into the header/nozzle assembly during upset conditions. The flow pattern of the constant diameter horseshoe-shaped header/nozzle assembly 175 is such that it will tend to force all fiber towards the back of the header/nozzle assembly where velocities are low and fiber settling is

more likely to occur. Again, as fiber accumulates, pressure drop increases and the driving force to get filtrate into the digester at the affected area decreases. It follows that most plugging occurs in the rear most nozzles; however, exceptions have been observed (e.g., nozzle plugging caused by column thickening that was caused by an event within the digester, such as a plugged circulation screen).

It is possible to unplug the horizontal nozzles 66a-l by closing back the manual isolation valves on the unplugged nozzles. This forces flow through the plugged nozzles thus flushing out the plugging material and/or preferentially diluting the column where it is required most. Manual flushing of plugged nozzles is labor intensive and may have to be performed several times per day in order to keep them unplugged. Most mills do not practice header/nozzle assembly clean-outs on a regular basis. Even with all nozzles unplugged, since the standard design does not permit monitoring and control of the individual flow rates, non-uniform introduction of filtrate is likely to occur.

The improved filtrate addition system according to this invention corrects for the above-mentioned problems by installing individual flow measurement and control devices, e.g., flow meters and flow control valves, corresponding to at least a plurality of header/nozzle assembly nozzles, and more preferably, corresponding to a majority of nozzles of the header/nozzle assembly. In its most preferred form, this invention corrects for the above-mentioned problems by installing individual flow measurement and control devices corresponding to each of the nozzles of the blow dilution header/nozzle overall assembly. The overall flow dilution header/nozzle assembly may comprise at least one horizontal or side dilution header/nozzle assembly and/or at least one bottom dilution header/nozzle assembly.

The flow meters and flow control valves are preferably computer-controlled to measure, monitor and/or control filtrate flow. Mechanical modifications (e.g., pipe extensions, pipe angles) to the header/nozzle assembly and nozzle piping may be required in order to give the required length of pipe for accurate flow measurement. However, these mechanical modifications and the installations therefore would be obvious to one skilled in the art and need not be described in detail herein.

The most preferred embodiment of the filtrate addition system of this invention is shown in **FIG. 3(b)**. The filtrate addition system has individual, automatic flow control valves and individual, in-line flow meters for each nozzle of the horizontal side header assembly 170, although the filtrate addition system may be applied to the bottom head dilution header/nozzle assembly 180 as well.

In particular, the horizontal side dilution header/nozzle assembly of **FIG. 3(b)** comprises a single inlet 16 branching to a relatively large, constant diameter, horseshoe header/nozzle assembly 170 with twelve (12) evenly spaced small diameter nozzles. The assembly 170 also includes an automatic valve 33 for overall flow adjustment, and a total flow indicator/transmitter device 44. Horizontal nozzles for assembly 170, each having an individual flow indication-control system, are shown at 76a-l.

FIG. 3(c) shows the preferred measurement and control system. In particular, each nozzle/flow indication-control system shown generally at 96 has a line 98 from the header 170 to digester shell 105. Moreover, the system 96 has an automatic valve 99 for individual flow adjustment, an individual flow indication/transmitter device 106 and a flow indication control loop 111.

The flow meters used are preferably magmeters; however, in-line orifice meters or external sonic-type meters could also be used. Similarly, automatic flow control using automatic ball valves via a flow-indication control (FIC) control loop (as shown in **FIG. 3(c)**) is preferred, but these valves may also be manual-type ball valves so long as flow indication devices are present for monitoring flows.

A significant portion of the benefit of this invention may also be obtained by using "split-header" arrangements, wherein there is a flow indication or flow-indication control (FIC) system for the flow going to every two (2), three (3), four (4) or six (6) or twelve (12) of the nozzles.

Under any circumstance, the nozzle and/or header piping design must provide the flow patterns and piping geometry required by the specific flow indication device. Further, it is of added advantage to elevate the horizontal side header up the digester in the blow dilution zone so that its elevation is higher than the elevation of the side dilution nozzle entry points. Ideally, the header should be at least 1 meter above, more preferably 1 to 2 meters above the side entry point elevation. Under

this circumstance, the nozzles branching from the header will be oriented vertically downward into the entry points. This difference in elevation will minimize fiber plugging of the header assembly during upsets with low digester pressure.

Methods for Measuring and Monitoring Filtrate Distribution Uniformity

Of the three typical filtrate introduction points in a conventional continuous digester, two–namely, the side dilution header/nozzle assembly and bottom dilution header/nozzle assembly-are external to the digester in the form of header/nozzle assembly/nozzle arrangements. In most applications, the individual nozzles are readily accessible. A plugged nozzle is characterized and can be identified by low temperature (from about ambient to about 40°C) as compared to nozzles with flow that will be from about 60 to about 85°C.

Typically, but not necessarily, there are 8 to 12 nozzles off the side dilution header/nozzle assembly and 4 to 8 nozzles off the bottom head dilution header/nozzle assembly of the blow dilution header/nozzle assembly. In this header/nozzle assembly configuration, it is quite unusual to find all nozzles clear and flowing. Of course, uniform filtrate distribution is optimal when all nozzles are clear. However, heretofore, instrumentation and/or devices for controlling an/or monitoring more than one individual nozzle flow was not present in digester systems.

Gross non-uniformity of filtrate distribution has been found to be directly related to circumferential temperature gradients in the digester wash and cook zones, and also in the blow line. Plugged nozzles are not the only cause for circumferential gradients. For example, partially plugged heating circulation screens will cause a similar effect.

Circumferential temperature gradients in the digester cook and wash zones cause a change in measured header/nozzle assembly temperature each time the switching valves change. Extraction and Modified Continuous Cooking (MCC™) header/nozzle assemblies both exhibit this cyclic behavior. In general, gradients greater than about 2°C indicate a cooking uniformity problem that is likely to affect reject content and screened yield. Measuring using a surface temperature device on the individual extraction and circulation nozzles gives a more precise indication of localized gradients.

Most wash screen header/nozzle assemblies are of the external, multiple-nozzle type configurations. In our experience, it is difficult to obtain meaningful data from these header/nozzle assembly temperatures. The reason for this is that the combined wash header/nozzle assembly temperature will fluctuate as much as about 20 to 30°C, regardless of whether or not there are circumferential non-uniformities caused by plugged filtrate addition nozzles. These macro swings in temperature are due to the fact that the wash screens are located in the vicinity of the upflow/downflow interface, and this interface is dynamic: moving in all of the vertical, circumferential, and radial planes. Thus, the flow through any individual nozzle will be regularly alternating between hot wash circulation zone liquor and cold blow dilution zone liquor.

Blowline circumferential temperature gradients of about 5 to 15°C are considered normal, whereas gradients in excess of about 35°C have been measured. Unplugging filtrate addition nozzles generally reduces these gradients. Most digesters are equipped with a single temperature probe and so blow line temperature gradients must be measured manually around the surface of the pipe near the outlet device. Remarkably, blow line temperature gradients are quite stable with time.

In severe cases, stable circumferential digester gradients are observed that extend from the blow dilution zone up to the extraction screen elevation. On MCC™ systems, it has been observed that plugging of several side dilution nozzles corresponded to localized hot spots on the same quadrant of the digester at the wash screen, the MCC™ screen, and the extraction screen elevations. Stable gradients in excess of 4°C that extend for more than 30 meters of column height and persist in spite of multiple circulations (i.e., the wash and modified circulations) are a strong indication of severe channel flow patterns. If the "hot" side of the digester vessel corresponds to the location of plugged filtrate addition nozzles, then it is a strong indication that non-uniform filtrate addition is a component of the problem.

Efficiency parameters, such as the wash Displacement Ratio (DR) vary strongly as a function of Dilution Factor (DF), contact efficiency, time, and temperature – in that order. Thus, if the intent is to measure the impact of non-uniform filtrate distribution, or contact efficiency, then variations in DF must be taken

into account. In practice, this means obtaining multiple sets of data and generating a DR vs. DF curve.

Component concentrations for liquor in the wash zone, for the filtrate, and for liquor in the blowline flow must be measured in order to calculate the wash DR. Component concentration testing is subject to considerable imprecision. It is difficult to obtain a representative blow lines sample. Normal variations in column movement and in filtrate inventory levels also cause large variations in component concentrations. Thus, in order to obtain meaningful data for comparative purposes a relatively large number of sample sets (e.g., > 30) have to be tested across the time frame of interest. Finally, the testing itself is resource intensive and so digester washing efficiency is typically not measured at most pulp mill sites. A major difficulty comes from the inability to directly measure the initial conditions at the beginning of the wash zone.

Digester internal heat recovery efficiencies are much easier to measure than washing efficiencies. Most mills are equipped with the on-line instrumentation required to measure heat recovery efficiencies in real time. Since both washing efficiency and internal heat recovery efficiency are directly related to the chip-to-filtrate contacting efficiency, it follows that washing and heat recovery efficiencies are strongly related to one another. One major difference between the two performance parameters, however, is in the effect of the wash circulation and heating system. An effective wash circulation system will increase washing efficiency but decrease heat recovery efficiency.

The Thermal Displacement Ratio (DR_T) for the bottom of the digester can be calculated using

$$DR_T = (T_{digester} - T_{blowline})/(T_{digester} - T_{filtrate}) \qquad [1]$$

where T denotes temperature, and the subscripts *blowline*, *filtrate*, and *digester* denote average temperatures for the digester discharge, the filtrate introduced in the blow dilution zone of the digester, and the digester zone immediately above the blow dilution zone (i.e., the wash screens–wash/cook zone).

The filtrate temperature refers specifically to the temperature of wash liquor introduced to the bottom of the digester. In many cases, 1st stage washer filtrate is

cooled in a cooler prior to introduction in the bottom of the digester. The cooler discharge temperature should be used to calculate DR_T.

The average digester temperature above the blow dilution zone cannot be measured directly but it can be estimated reasonably well by a radial average of the wash circulation temperature: i.e., the average between wash header/nozzle assembly and wash heater discharge temperatures. Alternatively, for digesters equipped with MCC™ circulations between the extraction and wash screens, a more robust estimate can be made based on a weighted average for the wash header/nozzle assembly, wash heater, and modified cook header/nozzle assembly temperatures. For example,

$$T_{digester} = ((T_{washcold} + T_{washhot})/2 + T_{modifiedcold})/2 \qquad [2]$$

Note that the "cold" temperatures here refer to header/nozzle assembly temperatures and not necessarily heater inlet temperatures. In many cases heater inlet flows include the addition of white liquor and if the temperature indicator is downstream of the liquor addition point it will result in understatements of both the digester temperature and the DR_T.

As with the wash DR, the thermal DR_T will vary strongly as a function of DF. The DR and DR_T vs. DF curves are very similar in form and magnitude, confirming that DR_T is a good indicator of both heat recovery and, to a lesser degree, washing efficiencies. As a reference point, the DR_T for a digester operating with a DF of between 0 and 0.5 t/admt is typically between 0.7 and 0.85. An ideal displacement would give a DR_T of slightly less than 1.00 at a DF of 0 t/admt.

It is also possible to measure heat recovery efficiency in a manner that measures energy losses directly, and is independent of DF. An energy balance around the blow dilution zone shows that

$$\text{BL Heat Loss} = (T_{blowline} - T_{filtrate})*\text{Blow flow} \qquad [3]$$

where BL Heat Loss is net energy losses out of the bottom of the digester at the blow line (expressed here as MMBtu/Badmt) and blow flow is the mass flow in the blow line. Strictly speaking, Equation [3] does not take into account differences is specific gravity and specific heat between the fiber and liquor phases within the blow flow. These differences will cause Equation [3] to understate blow line heat losses

by between 1 and 3%, but it is felt that this inaccuracy is minor relative to the inherent imprecision in flow and temperature measurements.

Examples

The following examples and experimental results are included to provide those of ordinary skill in the art with a complete disclosure and description of particular manners in which the present invention can be practiced and evaluated, and are intended to be purely exemplary of the invention and are not intended to limit the scope of what the inventors regard as their invention. Efforts have been made to ensure accuracy with respect to numbers (e.g., amounts, temperature, etc.); however, some errors and deviations may have occurred. Unless indicated otherwise, temperature is in °C or is at ambient temperature, and pressure is at or near atmospheric.

In these examples, the base case was taken as the conditions found at the start of the investigation. At that time, six of the twelve (50%) of the nozzles were plugged. Once base case measurements had been taken, the filtrate addition nozzles were all manually flushed out. A trial period was then undertaken when pulp mill personnel regularly monitored for, and flushed out, plugged nozzles. This manual task required enormous effort and was clearly not sustainable. Results showed that maintaining all of the nozzles unplugged resulted in a dramatic reduction of digester circumferential gradients. Improvements in thermal DR and in blow line heat losses were also noted.

The following results compare base case operation, trial operation (with nozzles manually unplugged and monitored), and post-modification operation (e.g., with all nozzles automatically controlled to provide equal flow).

System Modification Effect on Heat Recovery Efficiency and Washing Capacity

Table 1 summarizes operating results for selected periods of particularly stable operations. This data realistically represents operations for pre-modification, trial, and post modification results. The data is based on hourly averages filtered to eliminate average blow rates of less than 1000 Badmt/d. The same grade of pulp was being produced in all three periods.

Table 1 shows that a significantly higher wash zone DF is being achieved with a modifications of this invention, even at the higher production rates. In fact, the average dilution factors reported for post-modification operations are higher than any ever previously experienced. The DF increased when the nozzles were unplugged and a further significant step-up occurred when flow control on individual nozzles equalized the flow. With each step-up, the blow consistency was increased as well as the split of filtrate to the bottom. Both of these actions were needed to keep the DF down to reasonable levels.

Table 1: Selected Periods of Stable Operation on a Softwood Grade (all values are filtered, composite averages):

Conditions	pre-modification *6 nozzles plugged*	pre-mod trial *all nozzles flowing*	post-modification *all nozzles flowing in control*
Hours of data	72	78	48
Production *(Badmt/d)*	1226	1191	1258
$T_{digester}$* (°C)	157.7	154.4	162.8
$T_{filtrate}$ (°C)	55.0	62.3	63.0
$T_{blowline}$ (°C)	80.0	85.1	84.5
Blow flow *(l/s)*	135	121	125
Consistency***(%)*	9.8	10.0	10.2
Flow to bottom *(% of total filtrate flow)*	28	31	44
Kappa	32.5	34.3	34.9
DF *(t/bdmt)*	0.42	1.00	1.81
DR_T	0.72	0.74	0.79
BL Heat Loss *(MMBtu/Badmt)*	1.15	0.90	0.76
MP Steam Draw *(t/Badmt)*	0.94	0.74	0.82

* *based on wash zone temperature probe.*
** *based on outlet device dP and calibration curve.*

The DR_T increased significantly from pre-modification to trial to post-modification. At the same time, the blow line heat losses decreased. Thus, both digester heat recovery and digester DF capacity improved substantially with improvement in the uniformity of filtrate distribution. Furthermore, uniform flow with

control through all nozzles results in an incremental improvement over unmonitored, uncontrolled flow through all nozzles.

Note the post-modification steam usage is higher than the trial. This apparent anomaly is related to differences in DF. The thermal DR and the digester heat recovery efficiency both increase with increasing DF. However, as DF increases, more filtrate is introduced into the digester cook zones and the system's overall heating duty increases. Thus there are trade-offs between heat recovery efficiency, overall steam demand, and washing efficiency, all of which increase as DF rises.

FIG. 4 compares the DR_T versus DF curves for the three operating conditions. Of particular interest is the large variability in both DF and DR_T. The shape of the DR_T versus DF curve depicted in **FIG. 4** is similar to those observed in practice.

It is commonly known that wash zone DF for a digester with counter-current washing will have large variability and is difficult to control. The observation that the DR at any given DF can also vary, however, is novel and relevant. For example, **FIG. 4** shows that for pre-modification conditions at a net DF of 0.25 t/bdmt, the thermal DR ranged from approximately 0.62 to 0.75. This is an enormous difference in efficiency for the same amount of wash water application. It is reasonable to assume that washing efficiency and heat recovery efficiency will respond in a similar manner: i.e., at a given, constant DF, the washing efficiency is also expected to vary significantly.

The washing and heat recovery efficiencies at any given DF will depend on the chip-to-filtrate contacting efficiency and thus on chip and liquor flow patterns. Thus, variability in DR at any given DF is related to non-uniformity in chip and/or liquor flow patterns.

FIG. 4 shows that wash DF capacity increased sequentially in moving from pre-modification, to trial, to post-modification conditions. Most improvements in heat recovery efficiency appear to be related to this increase in DF. In moving from pre-modification to trial conditions, little or no effect was observed on the variability of DF at constant DR. Moving from trial conditions to post-modification conditions (where filtrate addition flows were monitored and controlled) resulted in a significant decrease in DR variability. This is consistent with the notion that controlling filtrate addition improves the uniformity of chip and liquor flow patterns. Table 2 summarizes variability data for DR_T and DF.

The change in filtrate addition conditions did not result in an appreciable shift in the DR versus DF curve. Such a shift was, however, observed in the blow line heat loss versus DF curve (**FIG. 5**). Changing conditions from plugged to unplugged nozzles resulted in a significant decrease in absolute heat losses for a given DF. Again, as DF increased, absolute heat losses also decreased.

Note that blow line heat losses are directly related to filtrate cooler duty since the filtrate cooler is used to cool the blow line temperature to a target set point. Filtrate cooler duty is in turn directly related to warm water generation and warm water temperature. In this example, decreasing the amount of warm water generated in this cooler and increasing its temperature has a pronounced, positive effect on the mill's overall energy balance. As **FIG. 5** shows, blow line heat losses and filtrate cooler duty were decreased by more than 25% as a result of the filtrate header/nozzle assembly modification.

Table 2: Effect of Filtrate Distribution on DR and DF Values and Variability.

Conditions	pre-modification *6 nozzles plugged*	pre-mod trial *all nozzles flowing*	post-modification *all nozzles flowing in control*
Hours of data	72	78	48
Avg DF (t/bdmt)	0.42	1.00	1.81
DF std. dev.	0.52	0.68	0.66
DF variance (%)	122	67.5	35.6
Avg DR_T	0.72	0.74	0.79
DR_T std. dev.	0.04	0.04	0.03
variance (%)	5.6	5.6	4.0
DR_T values at Average DF near 0.25 t/bdmt:			
Hours of data	39	20	20
Avg DR_T	0.72	0.74	0.78
DR_T std. dev.	0.03	0.03	0.01
DR_T variance (%)	4.3	4.3	1.9
minimum	0.63	0.68	0.76
maximum	0.78	0.79	0.81
range	0.15	0.11	0.05

Values are based on filtered, hourly averages.

The filtrate header/nozzle assembly modification resulted in improved heat recovery efficiency and decreased blow line heat losses. The effect on steam

usage, while positive, was not as dramatic as on recovery efficiency. This is because increased wash zone dilution factor leads to increased digester heating duty within the cook zones.

FIG. 6 shows the relationship between medium pressure steam demand and wash DF for different operating conditions. Again, a clear improvement is seen when comparing operations with unplugged filtrate nozzles to the pre-modification condition with plugged nozzles. It is interesting to note that in **FIG. 6** the slope of the function seems steeper for conditions with plugged nozzles as compared to unplugged nozzles. This suggests that running to higher DF's with plugged nozzles, if it is even possible to raise DF, comes at a progressively higher steam penalty than when operating with unplugged nozzles. Presumably, this is due to poor contacting efficiency and channel flow patterns. For operations with unplugged nozzles, the slope is approximately 0.09 ton of steam per ton of filtrate. Heating up one ton of filtrate from about 60 to 160°C in a heat exchanger would require 0.16 ton of MP steam. The difference (0.16 – 0.09 tons of steam) represents the effect of heating filtrate via chip-to-filtrate contacting.

The modification did not have an appreciable effect on blow line circumferential temperature gradients. **FIG. 7** is a sample of the extensive manual testing performed around a digester of **FIG. 1**. The gradient ranges from about 10 to about 40°C. The gradient is remarkably stable with time and has not been eliminated by the modification of this invention. Extensive analysis of normal operating data as well as data from process trials (involving changes to the wash circulation flow and filtrate distribution pattern) was performed in an effort to identify the primary source of this gradient. The conclusion is that the localized hot spot in the digester corresponds to hot stock in the center of the digester. The digester diameter is 8.5 m (28 ft). For the given vessel and header/nozzle assembly geometry, it is felt that filtrate addition, regardless of its uniformity, simply is not reaching the center of the vessel in time to quench the stock there. Elimination of this gradient would result in further improvements in heat recover efficiency.

One final consideration with respect to heat recovery is that the blow line temperature set point was deliberately increased from about 80°C to 85°C after the nozzles were unplugged. Increasing blow line temperature results in a significant improvement in the digester hot water energy balance. Furthermore, increasing this

temperature is known to increase the efficiency of the downstream brownstock diffuser washer. Prior to the filtrate header/nozzle assembly modification, it was not possible to raise the set point to the preferred 85°C. The temperature variability was so high that the temperature controller at that set point could not prevent excursions above 92°C. If blow temperature exceeds about 92°C, then the downstream atmospheric diffuser must be diverted resulting in significant upsets to the brownstock washing and oxygen delignification systems.

For the pre-modification, trial, and post-modification periods, the variances in blow temperatures were 0.92%, 0.86%, and 0.44%, respectively. Blow temperature is controlled by the filtrate cooler. Values for variance in filtrate temperature were 11.4%, 9.8%, and 3.0%, respectively. Improved DF, DR, and blow line temperature control are indicative of several improvements in overall process stability. It is important to note that comparisons between pre and post-modifications are being made at substantially different wash DF values. In the pre-modification period, it is certain that operating with average DF's greater than 1.0 t/admt could not be achieved with stable operation at these production rates.

The digester wash DF has increased by more than 400% and the effectiveness of digester DF has improved (according to DR_T results). At the same time, the blow line temperature and consistency have both increased with improved control. It is commonly known that higher inlet consistency and temperature will improve atmospheric diffuser efficiency.

Effect on Cooking Uniformity

FIGS. 8 and **9** illustrate the effect of the filtrate header/nozzle assembly modification on digester circumferential temperature gradients. **FIGS. 8** and **9** are typical of the observations noted whenever the filtrate header/nozzle assembly nozzles are unplugged: digester temperature gradients disappear. In the case with 6 of 12 nozzles plugged, gradients in excess of about 3 to 4°C are present in the digester's lower cook zones. Of course, this type of temperature difference will have a pronounced effect on pulping kinetics. Hence, these gradients will have a major effect on cooking uniformity.

FIG. 10 is blow line reject data. This data shows that overall cooking uniformity has improved since the header/nozzle assembly modification eliminated

digester circumferential temperature gradients. The regression curves suggest reject content within the normal kappa range may have decreased by as much as 1% on pulp. Note that the pre-mod data with six plugged nozzles is the worst-case situation in these examples.

Throughout the data collecting period for the post-modification, the system kept all nozzles unplugged, and flow to all nozzles equal. An interesting observation is that the individual valve positions vary significantly on a continuous basis. Thus continuous, major control action may be required to avoid non-uniform flow rates in these nozzles. Moreover, the system has never failed to equalize all 12 individual flows.

According to this data, the average blow line consistency target has been raised from about 10% to about 11.5%. Consistency control appears to be easier to achieve, i.e., less control action is required. In addition, blow temperature and filtrate temperatures have both been raised without compromising control. The higher filtrate temperature has resulted in significant improvements in the mill's warm/hot water energy balance.

Normalized medium pressure steam demand has decreased marginally, but higher dilution factor and thus higher digester heating duty offsets much of the potential steam savings from improved heat recovery. This is due to the test mill's choice to run to higher DF to improve washing. The improved wash allows a higher production rate by reducing the amount of filtrate bypassing the digester. This reduces the total wash water required. The evaporators can be the mill bottleneck.

Uniform filtrate addition via the system and method of this invention, therefore, results in higher blow line consistency, increased digester DF capacity, and improved heat recovery efficiency. Digester circumferential temperature gradients have been eliminated. A corresponding decrease in reject content has been observed suggesting significant improvements in cooking uniformity and screened yield. And blow line circumferential temperature gradients were not eliminated by the filtrate header/nozzle assembly modification.

This invention has been clearly described in detail, with particular reference to certain preferred embodiments, in order to enable the reader to practice the invention without undue experimentation. Theories of operation have been offered to better enable the reader to understand the invention, but such theories do not limit

the scope of the invention. In addition, a person having ordinary skill in the art will readily recognize that many of the previous components and parameters may be varied or modified to a reasonable extent without departing from the scope and spirit of the invention.

Furthermore, titles, headings, examples or the like are provided to enhance the reader's comprehension of this document, and should not be read as limiting the scope of the present invention. Accordingly, the invention is defined by the following claims, and reasonable extensions and equivalents thereof.